PIPE BURSTER WITH SPHERICAL BURSTING MEMBER

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application Number 60/493,957 filed August 8, 2003, the contents of which are incorporated fully herein by reference.

FIELD OF THE INVENTION

[0002] This invention relates generally to preparation for trenchless replacement of old pipe, and in particular to the bursting or cutting of subterranean pipe to allow the insertion of new pipe therein.

SUMMARY OF THE INVENTION

[0003] The present invention is directed to a pipe-bursting apparatus for use with a drill string. The pipe-bursting apparatus comprises a frame connectable with the drill string and at least one substantially spherical pipe-bursting member. The spherical pipe-bursting member is supported by the frame and operable in response to movement of the drill string.

[0004] The present invention further includes a horizontal directional drilling system. The horizontal directional drilling system comprises a drive machine, a drill string having a first end and a second end, and a pipe-bursting apparatus. The first end of the drill string is operatively connected to the drive machine and the pipe-bursting apparatus is operatively connected to the second end of the drill string. The pipe-bursting apparatus comprises a frame operatively connected to the drill string and at least one substantially spherical pipe-bursting member. The spherical pipe-bursting member is supported by the frame and operable in response to movement of the drill string.

[0005] Finally, the present invention includes a method for bursting pipe using a horizontal directional drilling system. The horizontal directional drilling system includes a rotary drive machine, a drill string having a first end and a second end, and a pipe-bursting apparatus operatively connected to the second end of the drill string. The first end of the drill

string is operatively connected to the rotary drive machine. The pipe-bursting apparatus comprises a frame and a spherical pipe-bursting member supported by the frame. The method comprises operating the spherical pipe-bursting member by rotating the drill string.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 is a diagrammatic representation of a near surface horizontal directional drilling machine acting on an uphole end of a drill string that, in turn, supports a pipe-bursting apparatus constructed in accordance with the present invention connected to a replacement pipe.

[0007] FIG. 2 is a fragmented, side elevational, partly sectional view of a pipe section used with a dual-member drill string.

[0010] FIG. 3 is a fragmented, side elevational, partly sectional view of a preferred rotary drive machine used with the present invention.

[0011] FIG. 4 is a side elevational, partly sectional view of a first embodiment of the pipe-bursting apparatus usable with a single-member drill string. A plurality of spherical pipe-bursting members are shown disposed about the circumference of the apparatus.

[0012] FIG. 5 is a side elevational, partly sectional view of another embodiment of the pipe-bursting apparatus of the present invention that is also usable with a single-member drill string. The apparatus of FIG. 5 shows the plurality of spherical pipe-bursting members disposed longitudinally along the axis of rotation of the pipe-bursting apparatus.

[0013] FIG. 6 is a side elevational, sectional view of yet another embodiment of the present invention usable with a dual-member drill string. The pipe-bursting apparatus of FIG 6 is shown having a plurality of recirculating spherical pipe-bursting members. The recirculating action of the spherical pipe-bursting members is driven by rotation of the inner member of the dual-member drill string.

[0014] FIG. 7 is a side elevational, sectional view of an alternative embodiment of the present invention. The embodiment of FIG. 7 uses the inner member of a dual-member drill string to drive movement of longitudinally aligned spherical pipe-bursting members. The

pipe-bursting apparatus also has a pair of opposing cutting members used to cut the *in situ* pipe.

[0015] FIG. 8 is a fragmented, side elevational, partly sectional view of an alternative pipe-bursting apparatus. The apparatus of FIG. 8 has a plurality of spherical pipe-bursting members and a percussive tool operatively connected to the pipe-bursting apparatus.

[0016] FIG. 9 is a side elevational view of a pipe-bursting apparatus of the present invention. The apparatus of FIG. 9 has a plurality of spherical pipe-bursting members and a cutting member connected to the frame of the apparatus. Operation of the cutting member is driven by a rod supported by the frame.

[0017] FIG. 10 is a side elevational view of a pipe-bursting apparatus of the present invention. The pipe-bursting apparatus of FIG. 10 has a plurality of spherical pipe-bursting members disposed about the outer circumference of the frame of the apparatus. Operation of the pipe-bursting members of FIG. 10 is driven by a race connected to a rotatable rod supported by the frame.

[0018] FIG. 11 shows yet another embodiment of the present invention having a plurality of spherical pipe-bursting members. The apparatus of FIG. 11 has an eccentric cam supported by the rotatable rod. The cam is shown in a position to cause advancement of a portion of the spherical pipe-bursting members from the frame.

[0019] FIG 12 is a side elevational, sectional view of an alternative embodiment of the apparatus shown in FIG 11. The apparatus of FIG. 12 has a flywheel that causes vibration of the spherical pipe-bursting members.

[0020] FIG. 13 is a side elevational view of an embodiment of the pipe-bursting apparatus of the present invention. The apparatus of FIG. 13 is shown operatively connected to the downhole end of a dual-member drill string. The apparatus comprises a biasing member adapted to offset the pipe-bursting apparatus from the centerline of the *in situ* pipe.

[0021] FIG. 14 illustrates an alternative embodiment of the pipe-bursting apparatus of FIG. 13. The apparatus of FIG. 14 is connectable with the downhole end of a dual-member drill string such that the longitudinal axis of the frame is offset from the longitudinal axis of

the dual-member drill string. FIG. 14 further illustrates the use of a gearing arrangement to translate rotation of the inner member of the drill string to rotation of the rotatable rod.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] Trenchless replacement of *in situ* or existing subterranean pipelines provides an efficient and cost effective way of replacing aged pipe and/or expanding the capacity of existing pipe. Several devices have been developed to accomplish these objectives. However, there remains an ongoing need for improved pipe replacement tools.

[0023] Turning now to the drawings in general and FIG. 1 in particular, there is shown therein a horizontal directional drilling machine 10. FIG. 1 illustrates the usefulness of horizontal directional drilling by demonstrating that a replacement pipe 12 can be installed without the need for digging an open trench along the desired path. To install the replacement pipe 12, a drill string 14 is inserted through the old pipe 16 and emerges from an exit pit 18. The downhole end 20 of the drill string 14 is then coupled to a pipe-bursting apparatus 24 and the replacement pipe 12. The replacement pipe 12 is towed through the existing borehole 22 behind the pipe-bursting apparatus 24 as the old pipe 16 is burst 26.

[0024] Considerable force is necessary to burst the old pipe 16 and pull the new pipe 12 through the burst pipe 26. As used herein, "burst" or "pipe-bursting" means bursting, cutting, fragmenting, expanding or any other action which ruptures the old pipe 16 to permit replacement thereof. The present invention is directed to devices and methods for improving pipe-bursting and old pipe replacement operations.

[0025] The horizontal directional drilling machine 10 generally comprises a frame 28 for supporting a drive machine 30. The drive machine 30 is movably supported on the frame 28 between a first position and a second position. Movement of the drive machine 30, by way of an axial movement means (not shown), between a first position and a second position axially retracts or advances the drill string 14 and a pipe-bursting apparatus 24 through the borehole 22.

[0026] The drill string 14 is operatively connected to the drive machine 30 at an uphole end 32. The pipe-bursting apparatus 24 is coupled to the downhole end 20 of the drill

string 14. In the present invention the drill string 14 transmits torque and axial force to the pipe-bursting apparatus 24 to break-up the old pipe 16.

[0027] In accordance with several aspects of the present invention, the term drill string may either mean a single-member drill string or a dual-member drill string. Any drill string capable of transmitting torque and/or axial force to the pipe-bursting apparatus may be used. A single-member drill string for use in the present invention is disclosed in U.S. Pat. No. 5,799,740, the contents of which are incorporated herein by reference. A suitable dual-member drill string 14 may comprise a plurality of dual-member pipe sections and is described in U.S. Pat. No. 6,739,413, the contents of which are also incorporated herein by reference.

[0028] Turning now to FIG. 2, there is shown one of a plurality of dual-member pipe sections 34 comprising a dual-member drill string 14. The dual-member pipe section 34 comprises a hollow outer member 36 and an inner member 38 positioned longitudinally therein. The inner member 38 and outer member 36 are connectable with the inner members and outer members of adjacent dual-member pipe sections to form the dual-member drill string 14 (FIG. 1). The interconnected inner members may be independently rotatable of the interconnected outer members to drive operation of the pipe-bursting apparatus 24.

[0029] The outer member 36 is preferably tubular having a pin end 40 and a box end 42. The pin end 40 and the box end 42 are correspondingly threaded. The pin end 40 is provided with tapered external threads 44, and the box end 42 is provided with tapered internal threads 46. Thus, the box end 42 of the outer member is connectable to the pin end 40 of a like dual-member pipe section 34. Similarly, the pin end 40 of the outer member 36 is connectable to the box end 42 of a like dual-member pipe section 34.

[0030] The external diameter of the pin end 40 and the box end 42 of the outer member 36 may be larger than the external diameter of the central body portion 48 of the outer member. The box end 42 of the outer member 36 forms an enlarged internal space 50 for a purpose yet to be described.

[0031] The inner member 38 is preferably elongate. In the preferred dual-member pipe section 34, the inner member 38 is integrally formed and comprises a solid rod.

However, in some instances a tubular inner member 38 may be preferred for the transportation of drilling fluid along the inner member of the drill string.

[0032] Preferably, the inner member 38 of the dual-member pipe section is provided with a geometrically-shaped pin end 52 and with a box end 54 forming a geometrically-shaped recess corresponding to the shape of the pin end 52 of the inner member 38. As used herein, "geometrically-shaped" denotes any configuration that permits the pin end 52 to be slidably received in the box end 54 and yet transmit torque between adjacent pipe sections 34. The geometrically-shaped pin end 52 and box end 54 prevent rotation of the pin end 52 relative to the box end 64 when thus connected. A preferred geometric shape for the pin end 52 and box end 54 of the inner member 38 is a hexagon. The box end 54 of the inner member 38 may be pinned, forged, welded or attached to the inner member by any suitable means.

[0033] The pin end 52 of the inner member 38 is disposed within the box end 42 of the outer member 36. It will now be appreciated that the box end 42 of the outer member 36 forms an enlarged internal space 50 for housing the pin end 52 of the inner member 38. This arrangement facilitates easy connection of the dual-member pipe section 34 with adjacent pipe sections, the drill string 14, and the drive machine 30.

[0034] Turning now to FIG. 3, the drive machine 30 for driving operation of the pipe-bursting apparatus 24 is shown in more detail. Because the outer member 36 and inner member 38 rotate independently of each other, the drive machine 30 may have two independent drive groups for driving the outer members independently of the inner members. It will be appreciated that while the drive machine of FIG. 3 will be described for use with a dual-member drill string, a similar drive machine 30 having only one drive group may be used to drive rotation of a single-member drill string.

[0035] The drive machine 30 thus preferably comprises a carriage 56 supported on the frame 28. Supported by the carriage 56 is an outer member drive group 58 and an inner member drive group 60. The outer member drive group 58 drives the outer member 36. The inner member drive group 60 drives the inner member 38. The drive machine 30 also comprises a biasing assembly 62 for urging engagement of the pipe sections. A suitable drive

machine 30 having an outer member drive group 58 for driving the outer member 36, and an inner member drive group 60 for driving the inner member 38 is disclosed in more detail in U.S. Pat. No. RE 38,418, the contents of which are incorporated herein by reference.

[0036] Turning now to FIG. 4, there is illustrated therein a first embodiment of the pipe-bursting apparatus 24A for use with the previously described horizontal directional drilling system 10. The pipe-bursting apparatus 24A includes a frame 64 having a first end 66 and a second end 68 and a longitudinal axis 69. As seen in FIG. 4, the frame 64 of the present embodiment may generally be characterized as a conical housing which supports at least one substantially spherical pipe-bursting member 70. Preferably, a plurality of pipe-bursting members 70 are supported by the frame and disposed about the outer circumference of the housing. The pipe-bursting members 70 are disposed about the outer circumference of the frame 64 in a plane substantially perpendicular to the longitudinal axis 69 of the frame.

[0037] As illustrated in FIG. 4, the frame 64 is substantially conical such that the diameter of the housing increases from the first end 66 to the second end 68. Preferably, the greatest diameter of the frame is greater than the largest internal diameter of the old pipe 16. The large diameter of the housing forces fragments 26 of the old pipe 16 into the surrounding soil and allows for the replacement pipe 12 to be drawn into the borehole 22. The frame 64 may be constructed to include a connection member 72 to allow towing of the replacement pipe 12 (FIG. 1) into the borehole 22. An expander known in the industry may be used between the apparatus and the replacement pipe to facilitate installation of a larger replacement pipe.

[0038] In FIG. 4, the apparatus 24A is shown with a rod 74 supported by the frame 64. The rod 74 has internal threads 76 to provide a connection to the drill string 14 that is capable of transmitting torque from the drill string to the pipe-bursting apparatus 24A for rotating and positioning the apparatus within the borehole 22. Thus, the rod 74 is fixed to the frame 64 so that rotation of the drill string 14 is transmitted to the frame. Rotation of the drill string 14 and the pipe-bursting apparatus 24A will drive operation of the spherical pipe-bursting members 70 in a manner yet to be described. The rod 74 may have an internal passage 78 for transporting drilling fluid from the drill string 14. Outlet 80 is provided so

that drilling fluid transported through the drill string 14 and into the rod 74 may exit the apparatus into the borehole 22. Fluid outlets may also be directed to the spherical pipe-bursting members 70 for lubrication and cooling.

[0039] The frame 64 may have a plurality of host pipe cleaning elements 82 supported at the first end of the frame. The pipe cleaning elements may be carbide cutting elements adapted to remove obstructions and/or debris from the interior of the old pipe 16 before the old pipe is burst by the pipe-bursting members 70. Spoils produced by the cleaning elements 82 are washed away by drilling fluid exiting outlet 80.

[0040] The spherical pipe-bursting members 70 are supported in a track 84 that extends generally around the frame 64 so that the spherical pipe-bursting members are disposed about the circumference of the frame in a plane substantially perpendicular to the longitudinal axis 69 of the frame. The apparatus 24A of FIG. 4 may have multiple tracks disposed around the circumference of the frame 64. Two tracks 84 are shown in FIG. 4 to support the plurality of spherical pipe-bursting members 70 in two separate planes that are perpendicular to the longitudinal axis 69. The tracks 84 are formed to retain the spherical pipe-bursting members 70 within the tracks during operation of the apparatus 24A. However, the spherical pipe-bursting members 70 may be sized so that they are capable of movement within the tracks 84 as the apparatus 24A is rotated by the drill string 14 and within the old pipe 16.

[0041] In operation the drill string 14 is rotated by the drive machine 30. Rotation of the drill string is transmitted to the pipe-bursting apparatus 24A by the threaded connection 76. As the pipe-bursting apparatus 24A is rotated, the drive machine 30 also applies axial force to the pipe-bursting apparatus by either pulling or pushing the apparatus through the old pipe 16. The axial movement and rotation of the pipe-bursting apparatus 24A causes the pipe-bursting members 70 to roll within the tracks 84. The rolling action of the pipe-bursting members 70 as they engage the old pipe 16 converts much of the rigid pull or push load exerted on the pipe-bursting apparatus into concentrated radial loads. The concentrated radial loads produce high tensile hoop stress in the old pipe 16. Thus, as the old pipe 16 is engaged by the rolling spherical pipe-bursting member 70 the radial force exerted

on the old pipe exceeds that of a fixed angle cone bursting apparatus. It will be appreciated; however, that both rotating and axially moving the pipe-bursting apparatus are not required to cause bursting of the old pipe 16. For example, axial movement of the pipe-bursting apparatus 24A will cause rolling of the spherical pipe-bursting members 70 within the tracks 84 and provide the bursting action.

[0042] Turning now to FIG. 5 there is shown therein an alternative embodiment of the pipe-bursting apparatus of FIG. 4. The pipe-bursting apparatus 24B of FIG. 5 is shown having a frame 64 connectable with the drill string 14 (FIG. 1) and a plurality of pipe-bursting members 70. The frame 64 is connectable with the drill string 14 using a threaded connection 76 supported on a rod 74. The rod 74 is supported by the frame 64 to transmit rotation and axial movement of the drill string to the pipe-bursting apparatus 24B.

[0043] A connection member 72 is shown supported by the frame 64 and connected to the replacement pipe 12. The connection member 72 pivotally connects the replacement pipe 12 to the frame 64 so that the replacement pipe may be towed into the borehole 22 as the pipe-bursting apparatus 24B is axially advanced. The connection member 72 may have a bearing assembly 88 that allows the pipe-bursting apparatus 24B to rotate, relative to the replacement pipe 12, in response to rotation of the drill string. Further, the pivotal connection point 90 allows the relationship between the longitudinal axis 69 of the pipe-bursting apparatus 24B to change relative to the longitudinal axis 92 of the replacement pipe 12 without placing unnecessary stress upon the connection member 72 or the replacement pipe.

[0044] The spherical pipe-bursting members 70 are longitudinally aligned on the frame 64 in tracks 86 that are generally axial with the longitudinal axis 69 of the frame. A preferred configuration may have four separate tracks 86 spaced equidistant about the circumference of the frame and sized to hold three pipe-bursting members 70 each. However, it will be appreciated that the number of tracks 86 and spherical pipe-bursting members 70 may be varied to suit the size and type of old pipe 16 and replacement pipe 12.

[0045] Referring now to FIG. 6 there is illustrated therein a pipe-bursting apparatus 100 that is connectable with a dual-member drill string 14. The pipe-bursting apparatus 100 generally comprises a frame 102, a rod 103 supported within the frame, and at

least one spherical pipe-bursting member 70 supported by the frame. The spherical pipe-bursting member 70 is operable in response to movement of the drill string 14.

[0046] The frame 102 may be generally elongate having a first end 104 and a second end 106. The first end 104 of the frame 102 has internal threads 108 for connecting the apparatus 100 to the pin end 40 of a correspondingly threaded outer member 36 of a dual-member drill string 14 (FIG. 2). The frame 102 may comprise a substantially conical housing having a smaller diameter at its first end 104 and a larger diameter at the second end 106.

[0047] The frame 100 is generally constructed to have two tracks 110 for supporting a plurality of pipe-bursting members 70 on the frame. The tracks 110 are comprised of a pipe engaging segment 112, a return segment 114, and an internal channel characterized as a drive segment 116. The pipe engaging segment 112 is generally axial with the longitudinal axis 69 of the apparatus 100 and extends lengthwise along an outer surface 118 of the frame 102 and supports the spherical pipe-bursting members 70 for engagement with the old pipe 16. The spherical pipe-bursting members 70 are driven along the pipe engaging segment 112 in the direction indicated by arrow 120 by in a manner yet to be described.

[0048] The rod 103 is rotatably supported by the frame 102 and connectable with the inner member 38 of the drill string 14. Bearings 122 support the rod 103 within the housing for co-axial rotation therein. Preferably, the rod 103 may comprise a geometrically-shaped pin end 124 at one end and a connection member 125 at the other. The geometrically-shaped pin end 124 provides for easy connection with a correspondingly-shaped inner member 38 (FIG. 2). The use of a geometrically-shaped pin end 124 to connect the rod 103 to the inner member 38 is preferred; however, connection may be accomplished in any way that allows for torque transmission from the inner member of the drill string to the rod 103. The rod also may have an internal passage 126 for delivering drilling fluid to the tracks 110 of the apparatus 100. Drilling fluid is used to lubricate the spherical pipe-bursting members 70 and the rod 103, and to wash away debris.

[0049] In the present embodiment, the rod 103 may comprise a drive member adapted to move the spherical pipe-bursting members 70 linearly along the longitudinal axis 69 of the frame 102. The drive member of rod 103 has a threaded segment 127 forming a series of

ridges 128 used to move the spherical pipe-bursting members 70 linearly and parallel to the axis of rotation 69 of the frame 102.

[0050] When the inner member 38 of the dual-member drill string 14 is rotated in a first direction, the threaded segment 127 of the rod 103 communicates with the spherical pipe-bursting members 70 present in the drive segment 116. This interaction causes the spherical pipe-bursting members 70 to travel in direction *X* as the rod 103 rotates. Moving the spherical pipe-bursting members 70 in direction *X* through the drive segment 116 causes movement of the spherical pipe-bursting members present in the pipe-engaging segment 112 and the return segment 114. Thus, rotation of the rod 103 causes the spherical pipe-bursting members to travel along the track 110 so that as the members travel the pipe-engaging segment 112 of the track within which they function to burst the old pipe 16.

[0051] In operation, the spherical pipe-bursting members 70 travel along the pipe engaging segment 112 until they reach the return segment 114. At the intersection of the pipe engaging segment 112 and the return segment 114 the spherical pipe-bursting members 70 turn towards the longitudinal axis 69 of the apparatus 100 and make their way to the drive segment 116. When the members 70 arrive at the drive segment 116 they encounter the rotating rod 103 and the ridges 128. As previously described, the ridges 128 push the spherical pipe-bursting members 70 in direction *X* which causes the members 70 within the pipe engaging segment 112 to roll in the direction indicated by arrow 120.

[0052] Turning now to FIG. 7, there is shown another embodiment of the pipe-bursting apparatus. The pipe-bursting apparatus 200 is connectable to a dual-member drill string and comprises a frame 202, a rod 204 rotatably supported on the frame, and a plurality of spherical pipe-bursting members 70 operable in response to rotation of the rod. The pipe-bursting members 70 are supported within tracks 206 and moveable around the tracks in response to rotation of the rod 204.

[0053] The frame 202 comprises an uphole end 208 having internal threads 210 for connecting the apparatus 200 to the pin end of a correspondingly threaded outer member of a dual-member drill string (FIG. 2). The uphole end 208 of the frame comprises a pipe cutting assembly 214 supported by the frame 202 and operable in response to axial movement of the

drill string. The pipe cutting assembly comprises bearings 218 and pipe cutting members 220. The pipe cutting members 220 are fixed to the frame 202 so that they are capable of rotating when the pipe-bursting apparatus is axially advanced along the old pipe. The pipe-cutting members 220 extend radially beyond the frame 202 a sufficient distance to allow the pipe-cutting members to score or cut the old pipe before the spherical pipe-bursting members 70 burst the old pipe. The pipe-cutting assembly further comprises an internal passage adapted to support the rod 204 for rotation therein.

[0054] The rod 204, having a first end 222 and a second end 224, is supported by bearings 218 within the internal passage for co-axial rotation therein. The first end 222 of the rod 204 may comprise the previously described geometrically-shaped pin end 226 for connection with a correspondingly shaped pin end of the inner member of a dual-member pipe section 34 (FIG. 2). The first end of the rod has an inlet 229 that directs drilling fluid into a generally elongate cavity 230. The cavity 230 transports drilling fluid to the tracks 206, the spherical pipe-bursting members 70 and the cutting members 220.

[0055] The second end 224 of the rod 204 may be integrally formed with the frame 202 and forms a generally conical housing 228 for supporting the spherical pipe-bursting members 70. The rod 204 and housing 228 are integrally formed so that rotation of the rod 204 by the inner member and axial movement of the apparatus 200 will drive movement of the spherical pipe-bursting members 70 about the track 206 and cause bursting of the old pipe.

[0056] In operation, the outer member 36 of the drill string is axially advanced through the old pipe so that the cutting members 220 are rolled along to score or cut the old pipe. The inner member 38 of the drill string is rotated to drive rotation of the rod 204. Rotation of the rod 204 causes the conical housing 228 to rotate about the longitudinal axis 69 of the apparatus 200. Rotation of the housing 228 will cause the pipe-bursting members 70 to roll along the tracks 206 while axial movement of the housing will increase the radial load and burst the old pipe.

[0057] Turning now to FIG. 8 there is shown therein another embodiment of the pipe-bursting apparatus of the present invention. In this embodiment, the pipe-bursting

apparatus 300 has a percussive assembly 302 connected to the frame 304. Percussive assembly 302 assists the bursting operation by supplementing the axial force applied to the pipe-bursting apparatus 300 by the drive machine 30 with a series of short, high intensity impacts. The percussive tool may comprise a pneumatically or hydraulically powered hammer assembly. The percussive tool may also be adapted for operation in response to rotation of a rod 306 supported by the frame 304. A suitable hammer assembly is described in U.S. Patent Application No. 10/139,304 entitled Rotary Driven Drilling Hammer, the contents of which are incorporated herein by reference. Fluid or air may be supplied to the percussive tool either through the rod 306 or through the replacement pipe 12 from the exit pit.

[0058] The pipe-bursting apparatus 300 may be constructed so that it is connectable to any dual-member pipe section 34 (FIG. 2). The pipe-bursting apparatus 300 comprises the frame 304 and the rod 306 rotatably supported within the frame. The frame 304 comprises internal threads 308 for connecting the apparatus to the pin end 40 of the outer member 36 (FIG. 2). The frame 304 is also adapted for connection to the replacement pipe 12 for towing the replacement pipe into the borehole as the pipe-bursting apparatus 300 is axially advanced. The rod 306 may comprise a geometrically-shaped pin end (not shown), as described with reference to FIG. 7. Bearings 310 support the rod 306 for rotation within the frame 304.

[0059] The general shape of the frame 304 is preferably conical, increasing in diameter from an uphole end 312 to a downhole end 314. The preferred conical shape of the frame 304 allows for the uphole end 312 to pass through the existing inner diameter of the old pipe with little resistance. However, the increase in diameter of the housing allows the spherical pipe-bursting members 70 to engage the old pipe with increasing tensile hoop stress as the apparatus 300 is axially advanced and the diameter of the housing increases.

[0060] The spherical pipe-bursting members 70 are supported by the frame 304 in tracks 316 for movement therein. The tracks 316 of apparatus 300 support the spherical pipe-bursting members so that the members are disposed about the circumference of the housing in a plane perpendicular to the longitudinal axis of the frame 304. A series of channels 318

transport drilling fluid to the spherical pipe-bursting members 70 from the rod 306 to lubricate the spherical pipe-bursting members and wash away debris.

[0061] As the pipe-bursting apparatus 300 is pulled back by the horizontal directional drilling machine 10, the replacement pipe 12 is pulled into the newly expanded borehole. The outer member of the drill string is rotated by the drive machine 30 to cause the spherical pipe-bursting members 70 to roll through the tracks 316. The inner member 38 transmits torque to the rod 306 by way of the connection between the rod and the inner member. Rotation of the rod is translated by the percussive assembly 302 into axial impacts upon the pipe-bursting apparatus 300. The axial impact forces generated by the percussive assembly assist the spherical pipe-bursting members 70 to burst the old pipe 16 as the replacement pipe 12 is pulled into position.

[0062] Referring now to FIG. 9, there is shown therein yet another embodiment of the present invention. The pipe-bursting apparatus 400 is connectable to a dual-member drill string and comprises a frame 402, a rod 404 rotatably supported on the frame, and a spherical pipe-bursting member 70. The spherical pipe-bursting member 70 is supported on the frame 402 and operable in response to movement of the drill string. The embodiment of FIG. 9 illustrates the use of a cutting member 406 comprising a plurality of cutting teeth 408 and positioned in advance the plurality of spherical pipe-bursting members 70 to cut the old pipe and remove debris from the borehole.

[0063] The frame 402 comprises a generally conical housing having a first end 408 and a second end 410. The first end 408 of the frame 402 may have threads for connecting the frame to the outer member of a dual-member drill string. The frame 402 has an internal passage 412 that extends along the entire length of the frame. The passage 412 has several branch channels 414 that carry drilling fluid to the spherical pipe-bursting members 70.

[0064] Spherical pipe-bursting members 70 are supported by the frame 402 in a plurality of tracks 416 that are disposed about the circumference of the conical housing. The tracks 416 are sized to allow the spherical pipe-bursting members 70 to roll around the circumference of the frame 402. The tracks 416 support the spherical pipe-bursting

members 70 so that they are disposed about the frame 402 in a plane perpendicular of the longitudinal axis of the apparatus 400.

[0065] The rod 404, having a first end 418 and a second end 420, is supported by bearings 422 and 424 for co-axial rotation within the frame 402. The first end 418 of the rod 404 may be connectable with the inner member of a dual-member drill string in a manner previously described herein.

[0066] The second end of the rod 404 comprises the cutter 406 to cut the old pipe 16 (FIG. 1) and remove debris and/or obstructions from the borehole. The cutter 406 is shown positioned outside of the frame 402 so that as the apparatus 400 is advanced through the old pipe, the cutter is positioned in front of the spherical pipe-bursting members 70. The cutter 406 is integral with the rod 402 and rotatable in response to rotation of the inner member of the drill string. The cutter 406 may comprise a plurality of carbide tipped cutting members 426 used to cut the old pipe in advance of engagement with the spherical pipe-bursting members 70.

[0067] Turning now to FIG. 10, there is shown another embodiment of the pipe-bursting apparatus. In this embodiment, the pipe-bursting apparatus 500 comprises a race 502 supported by a rod 504 for rotation therewith. The race 502 is adapted to roll a plurality of spherical pipe-bursting members 70, disposed about the circumference of the frame 506, in response to rotation of the inner member of the drill string.

[0068] The pipe-bursting apparatus 500 comprises the frame 506 and a rod 504 rotatably supported within the frame. The frame comprises an uphole end 508 and a downhole end 510. The uphole end 508 comprises internal threads 512 for connecting to the pin end of a correspondingly threaded pipe section. The downhole end 510 of the frame 506 is adapted for connection to a swivel connector assembly 514. A pipe puller (not shown) may be attached to the connector assembly 514 for towing the new pipe into the borehole as the pipe-bursting apparatus 500 is axially advanced.

[0069] Referring still to FIG. 10, the rod may comprise the previously described geometrically-shaped pin end (not shown) for connecting the rod to the inner member of the drill string. Bearings 516 and 518 support the rod 504 for rotation within the frame 506.

[0070] The pipe-bursting apparatus 500 uses spherical pipe-bursting members 70 to burst the old pipe. The spherical pipe-bursting members 70 are supported on the frame 506 using tracks 520 and at least one race 502. The spherical pipe-bursting members 70 are adapted to be engaged by the rotating race 502, described hereinafter. The spherical pipe-bursting members 70 may be constructed from a durable resilient material such as case hardened steel which is capable of resisting the high tensile hoop stresses placed on the old pipe.

[0071] The race 502 is supported on the rod 504. The race 502 comprises a plurality of bearing surfaces having tracks 522 and channels 524 for transporting drilling fluid to the spherical pipe-bursting members 70 from the rod cavity 526. The race 503 is shown integrally formed with the rod 504 for fixed rotation therewith. However, it will be appreciated, that a removable race may be used for attachment to and removal from the rod 504.

[0072] The inner member drive group 60 of the drive machine 30 rotates the rod 504. Rotating the rod 504 causes rotation of the race 502 within the frame 506. Rotation of the race 502 causes rolling of the spherical pipe-bursting members 70 within the tracks 520. Rolling of the spherical pipe-bursting members 70 in conjunction with axial advancement of the apparatus to burst the old pipe.

[0073] Referring now to FIG. 11, there is shown a pipe-bursting apparatus constructed in accordance with the present invention. In pipe-bursting apparatus 600 of FIG. 11 the spherical pipe-bursting members 70 oscillate in and out of the frame 602 in response to rotation of the rod 604. The apparatus 600 comprises an eccentric cam 606 supported on the rod 604 for rotation therewith and adapted to advance the spherical pipe-bursting member from within the frame.

[0074] The pipe-bursting apparatus 600 may be constructed so that it is connectable with the downhole end of any dual-member drill string. The pipe-bursting apparatus 600 comprises the frame 602 and the rod 604 rotatably supported within the frame. The frame 602 connected to the outer member is generally conical and comprises a swivel connector 608 for towing the replacement pipe 12 (FIG. 1) into the borehole as the pipe-

bursting apparatus 600 is axially advanced. The frame 602 may further define an opening 610 through which the spherical pipe-bursting member 70 is advancable and retractable through the opening 610.

[0075] The pipe-bursting members 70 are supported by the frame 602 in a cavity 616 that holds the members within the frame but allows them to advance and retract in response to rotation of the rod 604 by the inner member. When the spherical pipe-bursting members 70 are retracted into the frame 602, the members extend into an internal chamber 618 defined by the frame.

[0076] The pipe-bursting apparatus 600 comprises the eccentric cam 606 supported on the rod 604. The eccentric cam 606 comprises a plurality of channels for transporting drilling fluid to the spherical pipe-bursting members 70. The cam 606 is supported on the rod 604 for fixed rotation therewith. Rotation of the eccentric cam 606 causes oscillating advancement of the spherical pipe-bursting members 70 through the opening 610 when the cam engages the members. When the spherical pipe-bursting members 70 are not engaged by the cam 606 the members are retracted into the frame's internal chamber 618 by the external force exerted against the members by the old pipe or borehole.

[0077] Turning to FIG. 12, there is illustrated an alternative embodiment of the pipe-bursting apparatus shown in FIG. 11. The pipe-bursting apparatus 700 is connectable to a dual-member drill string and comprises a frame 702, a rod 704 rotatably supported on the frame, and a spherical pipe-bursting member 70 operable in response to rotation of the rod. The embodiment of FIG. 12 shows the use of an eccentric flywheel 706 fixed to the rod 704 for rotation therewith. Rotation of the eccentric flywheel 706 causes vibration of the spherical pipe-bursting members 70 which is used to assist the members in the bursting operation. Vibration of the spherical pipe-bursting members 70 during the bursting operation helps to reduce frictional resistance exerted on the apparatus 700, enhances bursting operations, helps to stabilize the soil in the new borehole, and reduces frictional drag against the replacement pipe 12 being towed into the borehole.

[0078] Referring now to FIGS. 10 and 13, the pipe-bursting apparatus 500 of FIG. 10 is shown with a biasing tool assembly 528 connectable with the uphole end 508 of the

apparatus 500. The biasing tool assembly 528 allows corrections to the grade of the replacement pipe 12 to be made as it is towed into the borehole behind the apparatus 500. The biasing tool 528 comprises a plurality of opposing radially extending biasing members 530 and 532 adapted to offset the pipe-bursting apparatus from the centerline of the borehole (not shown). Biasing members 530 are longer than biasing members 532. Thus, as shown in FIG. 13, when biasing members 530 are at the twelve o'clock position shown in FIG. 13, the apparatus 500 is steered towards the six o'clock position.

[0079] In operation the outer member of the dual-member drill string is used to rotate the biasing members 530 and 532 supported on the outer member 534 of the biasing assembly 528 for steering. A beacon (not shown) comprising an orientation sensor may be used with the apparatus or the biasing assembly to sense and communicate the orientation of the biasing tool and the apparatus to the operator. Once the biasing assembly 528 is properly oriented, the inner members of the drill string are rotated by the drive machine 30 to rotate a drill string drive 536 of the biasing assembly. The drill string drive 536 is operatively connected to a rod drive 537 supported on the rod 504 to transmit rotation of the inner member of the drill string to the race 502 supported on the rod. When a grade correction is desired, the outer member of the drill string is selectively rotated to move the biasing members 530 into a new orientation and the apparatus is axially advanced.

[0080] Turning now to FIG. 14, there is shown therein an alternative embodiment of the biasing tool assembly 528 of FIG. 13. In the embodiment of FIG. 14 a plurality of opposing radially extending biasing members 540, of equal length, are supported by a housing 538. The biasing tool assembly 528A of FIG. 14 comprises the housing 538, and a drill string drive 536 connectable with a rod drive 537. The inner member drive 536 comprises a rod gear drive 542 adapted to matingly engage a gear 544 supported on the rod 504 of the pipe-bursting apparatus 500.

[0081] The gear relationship between the rod 504 and the inner member drive 536 translates rotation of the inner member of the drill string into rotation of the rod and thus rotation of the race 502 fixedly supported by the rod. This relationship between the inner member drive 536 and the rod 504 allows the longitudinal axis 69 of the frame 506 and the

longitudinal axis of the drill string 544 may be offset relative to each other. Thus, when the longitudinal axis of the drill string 544 is offset below the longitudinal axis 69 of the apparatus 500, as shown in FIG. 14, the apparatus may be axially advance while holding the biasing tool assembly 528A in fixed rotational orientation to make desired grade corrections. If no grade correction is necessary, the outer member of the drill string may be continuously rotated so that the apparatus 500 is not biased to one side of the borehole.

[0082] The present invention also comprises a method for bursting pipe using a horizontal directional drilling system 10. The method employs a horizontal directional drilling machine and a drill string. A pipe-bursting apparatus of the present invention is operatively connected to the second end of the drill string. Preferably one of the pipe-bursting apparatus 24A, 24B, 100, 200, 300, 400, 500, 600 or 700 as described herein, may be used in carrying out this method.

[0083] Having determined the need for replacing the old pipe 16 without digging a trench, the drill string 14 may be inserted through the section of old pipe to be replaced 16. The pipe-bursting apparatus is connected to the downhole end of the drill string 14 as it protrudes from the far end of the old pipe. After connecting the pipe-bursting apparatus 24 to the drill string 14, the apparatus is positioned within the old pipe by advancing, withdrawing or rotating the drill string. Once the pipe-bursting apparatus has been positioned, the drill string is rotated to and the apparatus is axially advanced to operate the spherical pipe-bursting members supported on the frame of the pipe-bursting apparatus.

[0084] If the method of the present invention is performed using a dual-member drill string, operation of the spherical pipe-bursting members may be driven by rotation of the inner member of the drill string. The pipe-bursting apparatus may be properly positioned by axially advancing and rotating the outer member of the drill string. Once positioned, the inner member of the drill string is rotated to drive operation of the spherical pipe-bursting members.

[0085] Various modifications can be made in the design and operation of the present invention without departing from the spirit thereof. Thus, while the principal preferred construction and modes of operation of the invention have been explained in what is now

considered to represent its best embodiments, which have been illustrated and described, it should be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically illustrated and described.